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ANALYTICAL AND NUMERICAL ANALYSIS OF INJECTION MOLDING TOOLS OF ASA POLYMERS

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ABSTRACT

This paper demonstrates the process of designing tools for injection molding of ASA polymers, conducted based on 3D model of requested work piece that was used in auto-industry, by using CAD/CAE/CAM software packages (CATIA, VISI Vero, Autodesk Mold flow and ANSYS). The focus of research was aimed at stages of synthesis and analysis during the process of tool design. During 3D geometric, modeling of tools was used available bases/catalogues of standard parts and subassemblies. Numerical analysis was performed of ASA polymer flow and numerical structural analysis of main plate of tools, and the results obtained by CFD and FEM methods of numerical analysis have been verified in relation to previously obtained results by analytical analysis. Final considerations confirm that methodology presented in this paper can be used during the design of similar tools for injection molding of ASA polymers in auto-industry, with noted benefits.

***KEYWORDS:** Tools Design, Injection Molding, ASA polymer, Analysis, CFD & FEM*

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Original Article

1. INTRODUCTION

The use of polymers over the last couple of decades has expanded in the world's industrial production [1]. The most significant application is in food, construction and automobile industry. Injection molding is one of the most important and the most complex processes when using polymers. With the process of polymer injection is obtained, ready-made multi-functional products of extremely complex structure, made within close tolerance field. Such products can vary in sizes (from extremely small to large) and various masses (from a few grams to several dozens of kilograms). [2]

Injection mold design of polymers represents an enormous challenge for a designer in modern age. It is required to design a tool that will be able to produce a large number of pieces in short time period, by using minimum expenditure of material, time, energy and money. Tools thereby should endure high temperatures and large loads, and products should be usable and qualitative. Due to a large number of influential parameters, there still has not been developed a unique mathematical model that would encompass the entire process of injection molding. However, mathematical models do exist that focus on individual segments, such as: arrangement of pieces

in molds, fluid flow, heat conduction, cost-effectiveness etc. Injection molding of polymers has reached its sudden expansion by the application of computers and CAD/CAE/CAM (**C**omputer-**A**ided **D**esign/**E**ngineering/**M**anufacturing) software packages, especially due to complexity of products [3–6].

2. SPECIFICITIES OF MATERIAL OF WORK PIECE

Based on 3D model of requested work piece (figure 1), made out of amorphous ASA (**A**crylonitrile **S**tyrene **A**crylate) polymer, it was necessary to develop 3D model of tools for injection molding of series from $250\ 000$ to $1\ 000\ 000$ pieces, and then to analyze it. The considered work piece is of relatively small size dimensions $(\sim 140 \mathrm{x} 35 \mathrm{x} 10)$ mm.

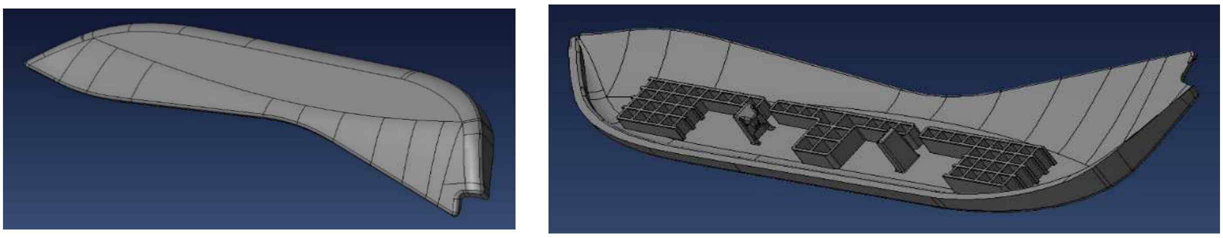


Figure 1: 3D Model of Work Piece.

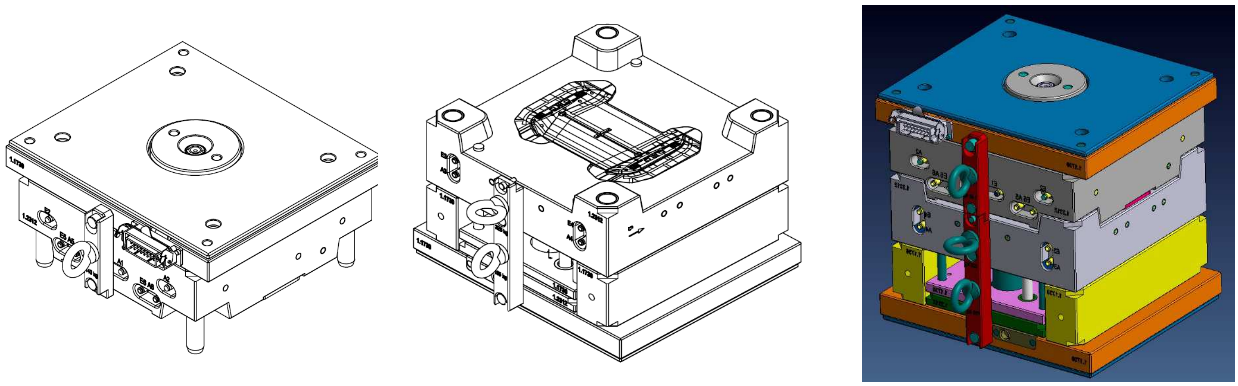
For the purpose of envisaging the behavior of materials during the simulation of injection molding process, in case of numerical analysis, it is especially important to know physical, mechanical and thermal characteristics of used polymers (VISI Vero Material Manager), as shown in table 1.

Table 1: Characteristics of ASA Polymers

Percentage of Contraction of Polymer $(\%)$	Temperature of Melting of Polymers $T_{t,p}$ $(°C)$	Ratio of Heat Conduction k $\left(\frac{W}{m \cdot K}\right)$	Density of Melted Polymer ρ $\left(\frac{kg}{m^3}\right)$	Thermal Capacity of Polymers c_p $\left(\frac{J}{kg \cdot K}\right)$
$0{,}4 \div 0{,}7$	250	$0{,}21$	950	$2\ 410$

3. SYNTHESIS OF TOOLS

In the process of tool design, it was important to take care of the following: defining of split plane and the arrangement of pieces in molds, defining of engraving and tools dimensions, problem solving of opening of tools, defining of filling and pouring system, defining and calculation of cooling system, defining and calculation of ejection system, and defining the system of ventilation of tools.



(a) (b) (c)

Figure 2: 3D Model of Tools for Injection Molding of ASA Polymer: (a) Subassembly of Upper Fixed Side (FS) of Tools; (b) Subassembly of Lower Movable Side (MS) of Tools; (c) Assembly of Complete Tool.

It is known that during cooling the polymer is contracted, which is why it was necessary to increase engraving in accordance with the percentage of contraction of ASA polymers. Specifically, it was selected the amount of percentage of contraction of ASA polymers of $0{,}6\ \%$ [1] (Table 1), and that means that 3D model of the work piece needed to be increased by the factor of scaling of $1{,}006$ when defining engraving. So, engraving at 3D model of tools is slightly increased in relation to 3D model of working piece due to its contraction during cooling.

Synthesis of tools, conducted by using CATIA and VISI Vero software packages, was based on maximum integration of standard parts and subassemblies (Mausburger catalogue). 3D model of injection molding tools of ASA polymers, after the completion of the stage of synthesis, is presented at figure 2. [7, 8]

4. TOOLS ANALYSIS

After creating 3D model of injection molding tools of ASA polymer, it is often performed analytical and numerical analysis of certain segments. In this paper, by using numerical analysis have been solved problems of flow of ASA polymers by using CFD (**C**omputational **F**luid **D**ynamics) method, as well as problems of structural analysis of the main plate of tools by using FEM (**F**inite **E**lements **M**ethod) method.

4.1 Analysis of Flow ASA Polymers

Injection molding of polymers is extremely complex process due to mutual activity of a large number of parameters (temperature, volume flow, pressure etc) [9–11]. That is why, it is almost impossible to envisage by analytical analysis the behavior of polymers during and after injection. By the occurrence of qualitative computers and software packages that support numerical simulations, this problem has become incomparably simpler for solving.

Parameters that were determined analytically and numerically in this paper, and then compared, during the analysis of flow of ASA polymer include: time of cooling of pieces of t_h and the Reynolds number Re.

Time of cooling of pieces of t_h, with temperature of ejection of pieces of $T_{izb.}$, is determined analytically in the following manner:

$$t_h{}^{ana.} = \frac{h^2}{\pi^2 \cdot \alpha} \cdot \ln\left(\frac{4}{\pi} \cdot \frac{T_{t,p} - T_{h,a}}{T_{izb.} - T_{h,a}}\right) = \frac{0{,}002^2}{\pi^2 \cdot 9{,}1 \cdot 10^{-8}} \cdot \ln\left(\frac{4}{\pi} \cdot \frac{250-60}{95-60}\right) \approx 8{,}6\ \mathrm{s} \tag{1}$$

where by:

$h \approx 2\ \mathrm{mm}$ – thickness of the thickest segment of piece,

$T_{t,p} = 250\,^\circ\mathrm{C}$ – temperature of melting of ASA polymer,

$T_{h,a} = 60\,^\circ\mathrm{C}$ – temperature of cooling of tools and

$T_{izb.} = 95\,^\circ\mathrm{C}$ – temperature of ejection of pieces of ASA polymers.

The ratio of thermal diffusion α of ASA polymers is calculated as:

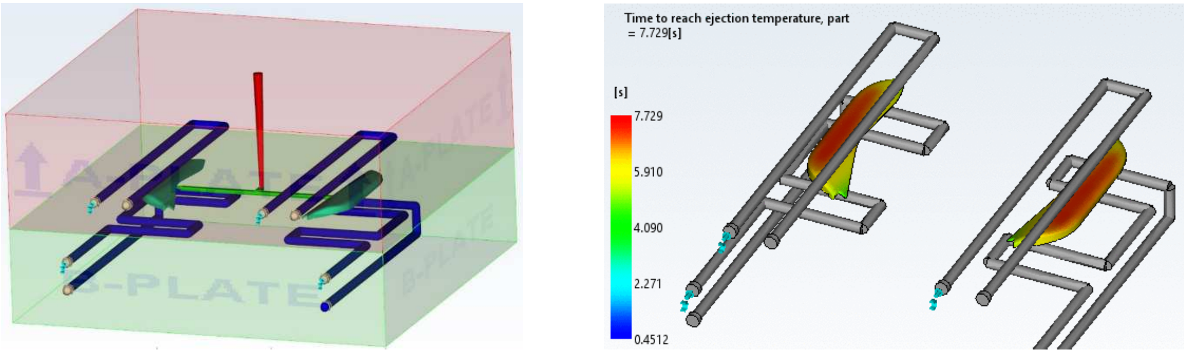
$$\alpha = \frac{k}{\rho \cdot c_p} = \frac{0{,}21}{950 \cdot 2\ 410} = 9{,}1 \cdot 10^{-8}\ \frac{\mathrm{m}^2}{\mathrm{s}} \tag{2}$$

where by: $k = 0{,}21\ \frac{\mathrm{W}}{\mathrm{m} \cdot \mathrm{K}}$ – ratio of heat conduction of ASA polymer,

$\rho = 950\ \frac{\mathrm{kg}}{\mathrm{m}^3}$ – density of melted ASA polymer and

$C_p = 2\,410\ \frac{\mathrm{J}}{\mathrm{kg}\cdot\mathrm{K}}$ – thermal capacity of ASA polymer.

For numerical analysis of flow of ASA polymers, a software package Autodesk Mold flow [12] (modules: Design Adviser, Gate Location, Molding Window, Fill + Pack, Runner Adviser & Runner Balance, Cool and Warp) was used. Time of cooling of pieces t_h, during temperature of ejection of pieces $T_{izb.}$, that was obtained by numerical analysis by using module Cool totals $t_h^{\,num.} \approx 7{,}7\ \mathrm{s}$ (Figure 3).



(a) (b)

Figure 3: Representation of Work Pieces and Cooling Systems (module Cool): (a) Completely Defined System of Cooling in Tool; (b) Time of Cooling of Pieces t_h, during the Temperature of Ejection of Pieces T_{izb}

Reynolds number, that will enable turbulent flow of fluids (water) in canals of cooling system, is determined analytically in the following manner:

$$Re^{ana.} = \frac{4\cdot\rho_h\cdot\dot{V}_h}{\pi\cdot\mu_h\cdot D} \approx \frac{4\cdot 1\,000\cdot 5{,}19\cdot 10^{-5}}{\pi\cdot 0{,}001\cdot 0{,}008} \approx 8\,260 \geq 4\,000 \tag{3}$$

where by:

$\rho_h = 1\,000\ \frac{\mathrm{kg}}{\mathrm{m}^3}$ – density of fluids (water) in canals of cooling system,

$\mu_h = 0{,}001\ \mathrm{Pa}\cdot\mathrm{s}$ – dynamic viscosity of fluids (water) and

$D = 8\ \mathrm{mm}$ – defined diameter of canal of cooling system.

The volume flow of fluids (water) by one circle of cooling system is $\dot{V}_h$ and it can be determined through the so-called „cooling power” by one circle $\dot{Q}_{kruga}$:

$$\dot{Q}_{kruga} = \dot{m}_h\cdot C_{p,h}\cdot\Delta T_h = \dot{V}_h\cdot\rho_h\cdot C_{p,h}\cdot\Delta T_h\ (\mathrm{W}) \tag{4}$$

$$\dot{V}_h = \frac{\dot{Q}_{kruga}}{\rho_h\cdot C_{p,h}\cdot\Delta T_h} \approx \frac{217{,}2}{1\,000\cdot 4\,187\cdot 1} \approx 5{,}19\cdot 10^{-5}\,\frac{\mathrm{m}^3}{\mathrm{s}} \approx 3\ \frac{\mathrm{lit}}{\mathrm{min}} \tag{5}$$

where by:

$C_{p,h} = 4\,187\ \frac{\mathrm{J}}{\mathrm{kg}\cdot\mathrm{K}}$ – thermal capacity of fluids (water) and

$\Delta T_h = 1\ \mathrm{K}$ – temperature difference of fluids (water) at the entry and exit of circle.

The power of cooling by one circle $\dot{Q}_{kruga}$ is calculated as:

$$\dot{Q}_{kruga} = \frac{\dot{Q}_{plastike}}{n_{krugova}} = \frac{868,7}{4} \approx 217,2 \text{ W} \tag{6}$$

where by:

$n_{krugova} = 4$ – number of cooling circles.

Power of cooling $\dot{Q}_{plastike}$ represents the total quantity of heat that needs to be exported during the time of cooling of pieces t_h:

$$\dot{Q}_{plastike} = \frac{Q_{plastike}}{t_h^{ana.}} = \frac{7\,471}{8,6} \approx 868,7 \text{ W} \tag{7}$$

Total quantity of heat $Q_{plastike}$ that is taken away from a piece and filler system is calculated as:

$$Q_{plastike} = m_p \cdot C_p \cdot \left(T_{t,p} - T_{izb.}\right) = 0,02 \cdot 2\,410 \cdot (250 - 95) = 7\,471 \text{ J} \tag{8}$$

where by:

$m_p = 0,02$ kg – total mass of ASA polymer.

Reynolds number Re obtained by numerical analysis totals $Re^{num.} = 8\,856$.

Table 2 shows obtained results of analytical and numerical analysis. Given that this concerns a 3D model, deviations of results are within tolerable borders.

Table 2: Comparison of Results obtained by Analytical and Numerical method for the Analysis of Flow of as a Polymer

Size	Analytical Method	Numerical Method	Relative Error (%)
t_h (s)	8,6	7,7	~10
Re	8 260	8 856	~7

4.2 Structural Analysis of the Main Plate of Tools

Tools for injection molding of polymers are exposed to large loads that occur due to injection molding of melted polymers under large working pressure. The design of tools should possess sufficient rigidity and strength in order to endure all loads, by preventing too large deflections.

Parameters that were determined analytically and numerically in this paper, and then compared, during structural analysis of the main plate include: deflection f and normal stress in the direction x axis σ_{xx}.

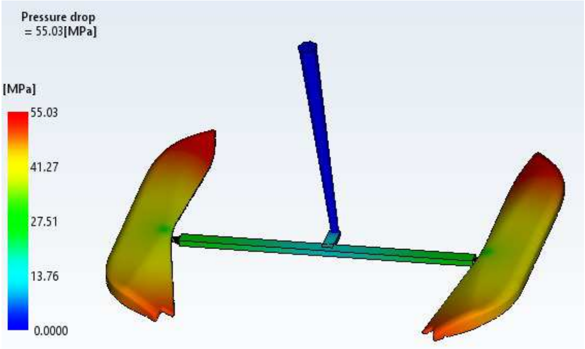
In order to determine the deflection and the stress of considered plate of the tool, it is necessary to know maximum pressure of the machine for injection molding $p_{max.}^{brizg.} = 243$ MPa (Krauss Maffei KM 110-390 C1) and the working pressure of machine for injection molding $p_{radni}^{brizg.}$. When a machine for injection molding operates with working pressure $p_{radni}^{brizg.} < p_{max.}^{brizg.}$ then its maximum capacity is not used, and thus energy consumption is reduced. Working pressure of the machine for injection molding $p_{radni}^{brizg.}$ is obtained in the manner that to a total pressure drop Δp is added additional, according to recommendations, 100 MPa to provide complete and qualitative filling-in of molds:

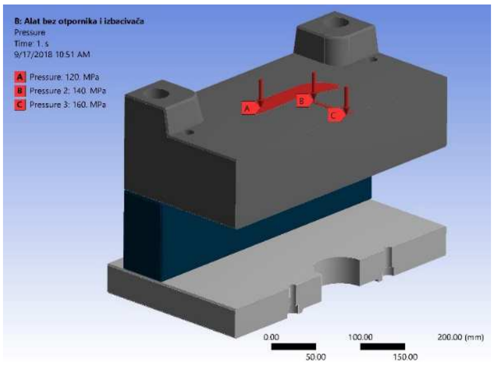
$$p_{radni}^{brizg.} = \Delta p + 100 \approx 60 + 100 \approx 160 \text{ MPa} \tag{9}$$

where by:

$\Delta p \approx 60$ MPa – total pressure drop (Figure 4a).

A total pressure drop is the consequence of flow of melted polymer through the canals of injector, filling and pouring system. It should not be larger than 100 MPa, given that injection molding machines provide maximum pressure even above 200 MPa. For determining of the total pressure drop a software package, Autodesk Mold flow (module Fill + Pack) was used. Working pressure of the machine for injection molding $p_{radni}^{brizg.}$ acts on designed surface of canal and moulds. Given that its value changes as the polymer flows through canal and molds, for the sake of simplicity, the total area was divided in three sub-areas in which different constant pressures operate ($p_C = 160$ MPa, $p_B \approx 140$ MPa and $p_A \approx 120$ MPa, Figure 4b).





(a) (b)

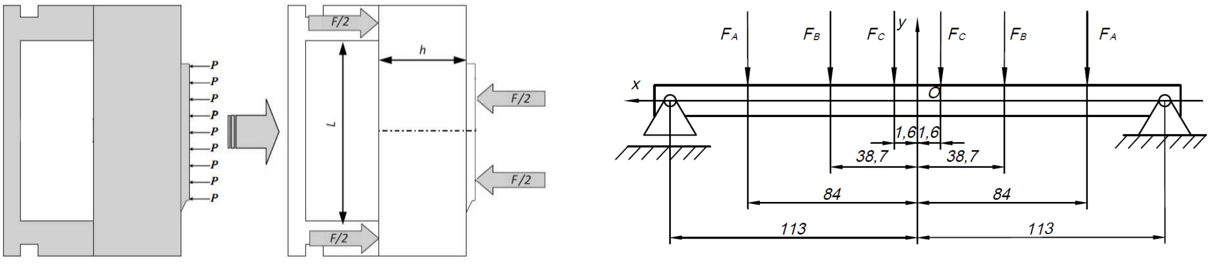
Figure 4: Total Pressure Drop Δp (a) and Arrangement of Pressures p_A, p_B and p_C to Three Sub-Areas (b).

During analytical calculation, the considered 3D plate is regarded as 2D beam. Figure 5 shows the simplified model, where working pressure of the machine for injection molding $p_{radni}^{brizg.}$ is replaced by concentrated forces F_A, F_B and F_C which operate in centers of mass of surfaces of sub-areas (defined in CAD software):

$$\begin{aligned} F_A &= p_A \cdot A_A = 120 \cdot 3\,365 = 403\,800 \text{ N} \\ F_B &= p_B \cdot A_B = 140 \cdot 348{,}6 = 48\,804 \text{ N} \\ F_C &= p_C \cdot A_C = 160 \cdot 84{,}9 = 13\,584 \text{ N} \end{aligned} \tag{10}$$

where by:

A_A, A_B and A_C – surfaces of sub-areas (defined in CAD software).



(a) (b)

Figure 5: Simplified Model (a) and the Arrangement of Concentrated Forces (b).

From theory of elastic lines, for the beam of length L, of axial rigidity $E \cdot I_z$, with two symmetric forces F that are distanced from support of beam for distance a, deflection f of the central point O is analytically determined in the following manner:

$$f = \frac{F \cdot L^2 \cdot a}{6 \cdot E \cdot I_x} \cdot \left[\frac{3}{4} - \left(\frac{a}{L}\right)^2\right] (\text{mm}) \tag{11}$$

That means that deflections caused by pairs of symmetric forces F_A, F_B and F_C:

$$f^{F_A} = \frac{F_A \cdot L^2 \cdot a_A}{6 \cdot E \cdot I_x} \cdot \left[\frac{3}{4} - \left(\frac{a_A}{L}\right)^2\right] = \frac{403\ 800 \cdot 226^2 \cdot (113-84)}{6 \cdot 210 \cdot 10^3 \cdot 17\ 644\ 848} \cdot \left[\frac{3}{4} - \left(\frac{(113-84)}{226}\right)^2\right] = 0{,}0197 \text{ mm}$$

$$f^{F_B} = \frac{F_B \cdot L^2 \cdot a_B}{6 \cdot E \cdot I_x} \cdot \left[\frac{3}{4} - \left(\frac{a_B}{L}\right)^2\right] = \frac{48\ 804 \cdot 226^2 \cdot (113-38{,}7)}{6 \cdot 210 \cdot 10^3 \cdot 17\ 644\ 848} \cdot \left[\frac{3}{4} - \left(\frac{(113-38{,}7)}{226}\right)^2\right] = 0{,}0053 \text{ mm} \tag{12}$$

$$f^{F_C} = \frac{F_C \cdot L^2 \cdot a_C}{6 \cdot E \cdot I_x} \cdot \left[\frac{3}{4} - \left(\frac{a_C}{L}\right)^2\right] = \frac{13\ 584 \cdot 226^2 \cdot (113-1{,}6)}{6 \cdot 210 \cdot 10^3 \cdot 17\ 644\ 848} \cdot \left[\frac{3}{4} - \left(\frac{(113-1{,}6)}{226}\right)^2\right] = 0{,}0018 \text{ mm}$$

where by:

$$I_z = \frac{b \cdot h^3}{12} = \frac{346 \cdot 84{,}9^3}{12} \approx 17\ 644\ 848 \text{ mm}^4 \text{ – axial moment of beam inertia.} \tag{13}$$

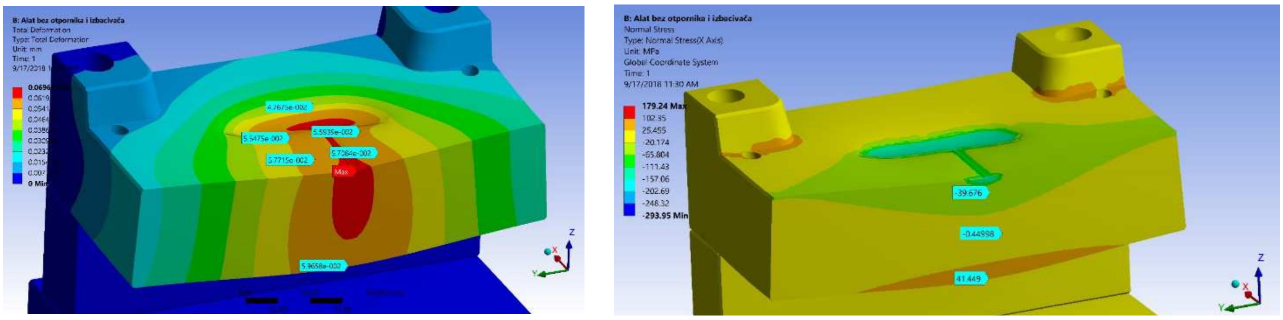
Total deflection f of the central point O (Figure 5) is analytically determined as:

$$f^{ana.} = f^{F_A} + f^{F_B} + f^{F_C} + \Delta f = 0{,}0197 + 0{,}0053 + 0{,}0018 + 0{,}026 \approx 0{,}053 \text{ mm} < 1 \text{ mm} \tag{14}$$

where by:

$\Delta f = 0{,}026$ mm – deflection due to deformability of support (defined in CAE software).

For numerical structural analysis of the main plate of tools software package ANSYS [12, 13] (module Static Structural) was used. Total deflection f of the central point O of the main plate of the lower movable side (MS) of tools obtained by numerical analysis totals $f^{num.} \approx 0{,}06$ mm (Figure 6).



(a) **(b)**

Figure 6: Deflections (a) and Normal Stress in the Direction of x Axis (b).

Normal stress σ_{xx} in the central point O (Figure 5), at lower fibers of beam is analytically determined in the following manner:

$$\sigma_{xx}{}^{ana.} = \frac{M_z^O}{W_x} \approx \frac{16\ 849\ 595}{415\ 662} \approx 40{,}5 \text{ MPa} \tag{15}$$

Moment M_z^O in the central point O is:

$$M_z^O = R_y \cdot 113 - F_A \cdot 84 - F_B \cdot 38{,}7 - F_C \cdot 1{,}6 \approx 16\ 849\ 595\ \mathrm{N \cdot mm} \tag{16}$$

Reactions in supports R_y, in case of beam with symmetric forces, are:

$$R_y = F_A + F_B + F_C = 403\ 800 + 48\ 804 + 13\ 584 = 466\ 188\ \mathrm{N} \tag{17}$$

Moment of resistance of beam inertia W_z is:

$$W_z = \frac{I_x}{|y_{max}|} = \frac{b \cdot h^3}{12} \cdot \frac{2}{h} = \frac{346 \cdot 84{,}9^2}{6} \approx 415\ 662\ \mathrm{mm^3} \tag{18}$$

Normal stress σ_{xx} in central point O of the main plate of the lower movable side (MS) of tool obtained by numerical analysis totals $\sigma_{xx}^{num.} \approx 41{,}5\ \mathrm{MPa}$ (Figure 6), not taking into consideration contact pressures that increase stresses.

Table 3 demonstrates obtained results of analytical and numerical analysis. Given that this concerns a 3D model, deviation of results are within tolerable borders.

Table 3: Comparison of Results obtained by Analytical and Numerical method for Structural Analysis of the Main Plate of Tools.

Size	Analytical Method	Numerical Method	Relative Error (%)
f (mm)	0,053	0,06	~13
σ_{xx} (MPa)	40,5	41,5	~2

In the end of process of designing tools were generated with complete technical documents, with focus on non-standard elements that will be produced. Thereby, it was also generated BOM (**B**ill **o**f **M**aterial) sheet, i.e. sheet of all accompanying parts with labels of materials. After making and testing of tools at the machine for injection molding Krauss Maffei KM 110-390 C1 [14], were successfully made physical prototypes of working piece (Figure 7).

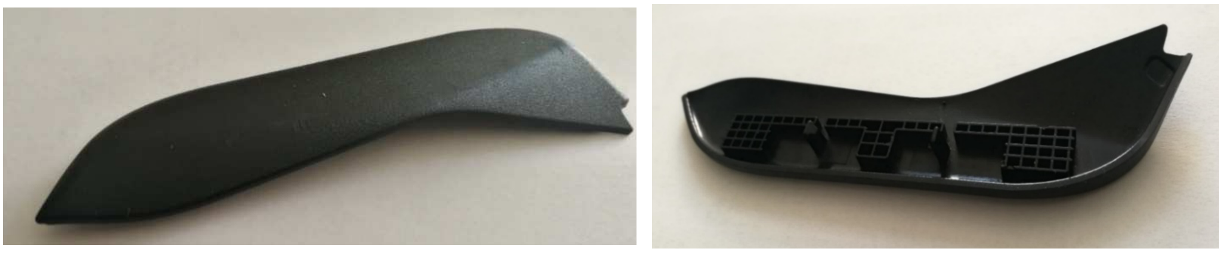


Figure 7: Physical Prototype of Working Piece.

5. CONCLUSIONS

Designing of tools in practice is mostly based on experience of a designer, and many measures are selected without considering mathematical models. Results obtained by the completion of this paper have confirmed close relation of experiential decisions and mathematical models. Mathematical models are being in larger scope implemented in solvers of softwares by which numerical analyses are made. Although such softwares are relatively simple to use, interpretation of obtained results has become one of the most demanding and the most complex tasks for modern designers. Therefore, the aim of this paper was to demonstrate and verify results obtained by numerical analysis in relation to previously obtained results by analytical analysis, which was achieved in the end. Selected are conclusions that ensued by the implementation of this paper:

- By the completion of this paper, it was proved that by the proper use of computer in all stages of process of design of tools for injection molding of ASA polymer can be reduced costs in relation to the conventional design for $(20 \div 30)$ %, time of tool production for $(30 \div 40)$ %, time of injection molding for $(20 \div 40)$ %, and material costs for $(15 \div 20)$ %. Total production cycle is thereby shortened for $(60 \div 70)$ %. Similar results have been confirmed by previously conducted researches.
- Results obtained by CFD method of numerical analysis, during flow of ASA polymers, are verified in relation to previously obtained results by analytical method. Relative error during cooling of pieces t_h obtained by numerical manner is ~ 10 % in relation to the value calculated analytically. Relative error for Reynolds number Re obtained numerically is ~ 7 % in relation to the value calculated analytically.
- Results obtained by FEM method of numerical analysis, during structural analysis of the main plate of tools, are also verified in relation to the previously obtained results by analytical method. Relative error for deflection f of the central point O of the main plate of the lower movable side (MS) of tools obtained by numerical manner is ~ 13 % in relation to the value calculated by analytical manner. Relative error for the normal stress σ_{xx} of the central point O of the main plate of lower movable side (MS) of tools gained by numerical manner is ~ 2 % in relation to the value calculated by analytical manner.

Generally speaking, modern engineering is placed at the crossroad of intense application of numerical methods in relation to analytical methods when solving engineering problems. Actually, scientists and young engineers are preparing the world for the complete transition to numerical simulations.

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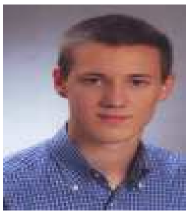
REFERENCES

1. *Zhou, H. (2013). Computer Modeling for Injection Molding: Simulation, Optimization, and Control. John Wiley & Sons, Inc., New Jersey.*
2. *Kazmer, D. O. (2007). Injection Mold Design Engineering. Hanser, Munich.*
3. *Mircheski, I., Łukaszewicz, A., & Szczebiot, R. (2019). Injection Process design for Manufacturing of Bicycle Plastic Bottle Holder using CAx Tools. Procedia Manufacturing, 32, 68–73.*
4. *IBRAHIM, F. (2015). Synthesis of smectic and discotic liquid crystals derivatives by flow injection system. Int J Nanotech Appl, 5, 9–16.*
5. *Mircheski, I., Lukaszewicz, A., Trochimczuk, R., & Szczebiot, R. (2019). Application of CAX system for design and analysis of plastic parts manufactured by injection moulding. In Proceedings of 18th International Scientific Conference „Engineering for Rural Development" (pp. 1755–1760). Jelgava, Latvia.*
6. *Miranda, D. A., & Nogueira, A. L. (2019). Simulation of an Injection Process Using a CAE Tool: Asessment of Operational Conditions and Mold Design on the Process Efficiency. Material Research, 22(2), e20180564.*
7. *Edabu, P. A. U. L., & Anumaka, I. B. (2014). Motivation tools as a determinant of effectiveness on academic staff in selected private universities in Central Uganda. International Journal of Research in Business Management, 2(9), 93–106.*

8. *Shi, X., Ni, X., Wang, Y., Wu, C., Li, R., & Gu, M. (2019). Injection Mold Analysis Based on Moldex3D Car dashboard back cover Casting System. IOP Conference Series: Earth and Environmental Science, 252, 022103.*
9. *Saric, I., Pervan, N., Muminovic, A., & Hadziabdic, V. (2018). Geometric and Mathematical Analysis of Forging Tools for Roller Bodies in Bearings. International Journal of Mechanical Engineering and Technology, 9(4), 624–633.*
10. *Saric, I., & Muminovic, A. (2018). Product Development and Design. Faculty of Mechanical Engineering Sarajevo, Sarajevo.*
11. *Pedagopu, V. M. (2013). Modelling, Manufacturing of Mold Tool and Plastic Flow Analysis of an Air Cooler Tank. International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), 3(3), 109–116.*
12. *Matarneh, R., Sotnik, S., & Lyashenko, V. (2018). Search of the Molding Form Connector Plane on the Approximation Basis by the Many-Sided Surface with Use of the Convex Sets Theory. International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), 8(1), 977–988.*
13. *Bakar, M. A., & Sah, J. M. (2018). Dynamic Response Analysis for Development of Flexible Lightweight Vehicle Chassis using CAE Tools.*
14. *Menges, G., Michaeli, W., & Mohren, P. (2001). How to Make Injection Molds (3rd ed.). Hanser, Munich.*
15. *Fu, J., & Ma, Y. (2019). A method to predict early-ejected plastic part air-cooling behavior towards quality mold design and less molding cycle time. Robotics and Computer Integrated Manufacturing, 56, 66–74.*
16. *Sao, N., & Mishra, R. (2014). Video Shot Boundary Detection Based On Nodal Analysis of Graph Theoritic Approach. International Journal of Management, Information Technology and Engineering (BEST: IJMITE), 15–24.*
17. *Saric, I., Pervan, N., Colic, M., & Muminovic, A. (2018). Conceptual design and stress analysis of the composite frame of Dirt Jump Mountain Bike. International Journal of Mechanical Engineering and Technology, 9(3), 204–213.*
18. *Michaeli, W., Greif, H., Kretzschmar, G., & Ehrig, F. (2001). Training in Injection Molding: A Text- and Workbook (2nd ed.). Hanser, Munich.*

AUTHOR'S PROFILE



Mr. Zejd Imamović got his Bachelor Degree in Mechanical Engineering, from the Faculty of Mechanical Engineering in 2016. In 2018. he got his Master Degree in the field of Mechanical Engineering - Mechanical Construction and Design Department. Since lately he has been Teaching Assistant at the same Faculty of Mechanical Engineering - University of Sarajevo, Mathematics and Physics Department - field of Computer Science in Mechanical Engineering - subject Programming I.

Beside teaching, Imamovic is also a web administrator of the Faculty's web site https://www.mef.unsa.ba/en/.

While being student in period from 2015-2017 he was teaching tutor at the Mechanics Department, teaching within subjects like Kinematics, Strength of Materials, and also taught these subjects at the summer school which was intended for preparing students for the semester.

As a new reasearcher, and future PHd student, he hasn't published any papers yet, but there are some articles in preparations for publishing. Also he is one of the authors of the two books that will be published in near future.

During and after the study, Imamovic finished plenty of online courses from the various online platforms like edx, coursera and udemy, and has earnedquite number of certificates from most prestigious Universities like: MIT, RWTH Aachen, Cornwell, Vanderbuilt and like so.

Zejd Imamović is also active sportsman, competing in Brazilian Jiu Jitsu, Grappling and Wrestling sports. He also held certificied 1st degree black belt degree in Taekwondo since 2014.

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Detail information and a CV can be found on the website of the Faculty of Mechanical engineering or LinkedIn where the links are given in the following text:

https://www.mef.unsa.ba/Home/nastavnoOsobljeDetalji/59

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The research interests of Professor Hadžiabdić are in the theoretical and applied aspects of difference equations and discrete dynamical systems, including the global behavior of solutions. He worked in differential equations with Stability, Bifurcation Analysis and Chaos. He deals with the study of PDJ and its application.

Papers of Professor Hadžiabdić can be found at the following links:

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